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High-Speed Operation of Step-Edge Vertical-Channel Organic Transistors

Kazuhiro Kudo[1], Tomoki Takano[1], Hiroshi Yamauchi[1], Masaaki Iizuka[2], Masakazu Nakamura[1]

[1]Chiba University, Graduate School of Engineering
1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan
Phone: +81-43-290-3322 E-mail: kudo@faculty.chiba-u.jp
[2]Chiba University, Faculty of Education
1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan

1. Introduction

Recently high performance electric and optoelectronic devices based on organic semiconductors have been demonstrated, such as organic light-emitting diodes (OLEDs), thin-film transistors (TFTs), and solar cells. These organic devices show promise for low-cost, large-area, and flexible devices. In particular, display panels using OLED are expected for mobile electronic devices, and excellent stability and high efficiency OLED have been reported. On the other hand, rapid progress of organic transistors has been made in recent years [1-3]. Furthermore, all-organic display devices are expected by combining the OLED with organic transistors [4-7], because organic transistors driving OLED are necessary to achieve flexible and large scale active-matrix displays. To be practical, however, it is necessary to operate with a drive voltage as low as a few volts and have sufficient reliability. Conventional organic field-effect transistors (OFETs) have low-speed, low-power, and relatively high operational voltage mainly due to their low-mobility and high-resistivity.

From these points of view, we have proposed vertical-type OFETs with a short channel length [4-6]. In this paper, we proposed a step-edge vertical-channel OFET (SVC-OFET) for achieving a short channel length by a simple fabrication procedure.

2. Experimental

The device structure and fabrication process are shown schematically in Fig. 1(a)-(c). First, Al gate electrodes lines (line width of 8 μm, thickness of 1 μm) were patterned on a glass substrate and covered with a 200 nm - thick SiO_2 film. Second, the pentacene thin film of 50 nm was deposited using vacuum evaporation technique at approximately 2×10^{-3} Pa. Finally, Au was deposited on the pentacene film by an incline vacuum evaporation technique to form the source and drain electrodes. The step edge of the gate electrode serve as a shadow mask and the short channel is formed at the step edge. The channel length corresponds to the thickness of the gate electrode, and the channel length is controlled by choosing the thickness of Al gate electrode. OFETs with a short channel length around 1 μm have been realized. The electrical characteristics were measured using semiconductor parameter analyzer (Agilent 4156C) in vacuum at room temperature.

As shown in Fig. 1(c), SVC-OFET has an asymmetric

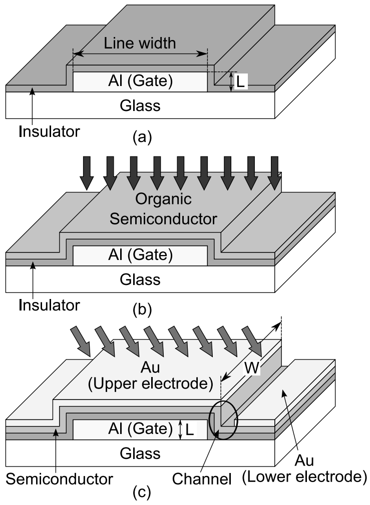

Fig. 1 Schematic views of the device structure and fabrication process.

device structure concerning the source and drain electrodes. It is therefore necessary to distinguish between the cases when the upper electrode is used as the source electrode (case 1) and when as the drain electrode (case 2). Figure 2 shows the SEM photograph around the step-edge region of SVC-OFET. In this case, the estimated gap between the upper and lower electrodes which corresponds to the channel length was approximately 1 μm. Capacitances of the gate - source and gate - drain electrodes are different by choosing the configuration, the upper (lower) electrode as a source (drain). Furthermore, the capacitance between the

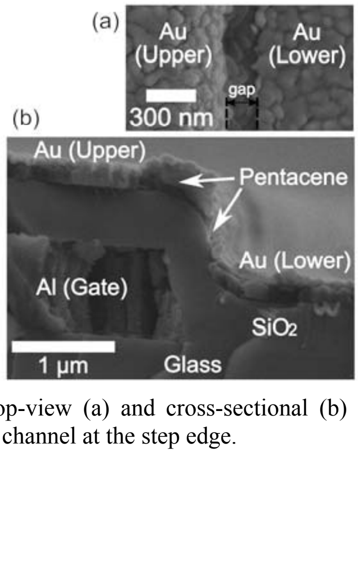

Fig. 2 Top-view (a) and cross-sectional (b) SEM images around the channel at the step edge.

upper electrode and gate electrode is controllable by changing the gate width. Typical capacitances of gate - lower electrode and gate - upper electrode were 0.3 and 2.3 pF/mm, respectively (gate electrode width; 8 μm). In this paper, all of the results were obtained with case 1 configuration. In case 1, the device can operate with higher speed than that of in case 2 because the parasitic capacitance between the gate and the lower electrode is much lower. On the other hand, an SVC-OFET in case 1 configuration has a smaller contact resistance than in case 2 because the carrier injection area in case 1 is larger.

3. Results and discussion

The static characteristics of a pentacene SVC-OFET are shown in Fig. 3. The drain-source current (I_{DS}) at constant drain-source voltage (V_{DS}) decreases with increasing the gate voltage (V_G). These characteristics are same as a typical p-channel pentacene OFET. The mobility and ON/OFF ratio were approximately 0.02 cm^2/Vs and 10^4, respectively.

Figure 4 shows frequency characteristics of the SVC-OFET. In this report, the frequency is ac input gate voltage and normalized output current is the ratio of the output I_{DS} at each frequency ($I_{DS}(f)$) to that at 100 Hz (I_{DS}(100 [Hz])). The cut off frequency (f_c) is defined here as the frequency where $I_{DS}(f)$ decreases to 3 dB down value from the I_{DS}(100 [Hz]); $20\log(I_{DS}(f_c)/I_{DS}(100\ [\mathrm{Hz}])) = -3$ [dB]. As a reference, the experimental data of a pentacene lateral-type FET with the channel length of 20 μm are also shown in Fig. 4. The control of pentacene crystal size and alignment is effective to improve the mobility of pentacene

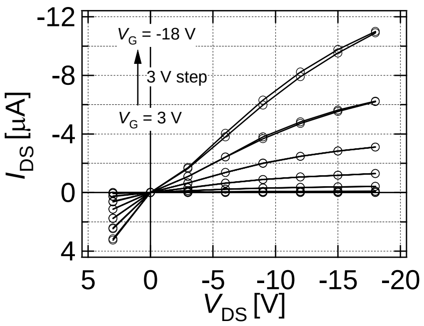

Fig. 3 Static characteristics of the pentacene SVC-OFET.

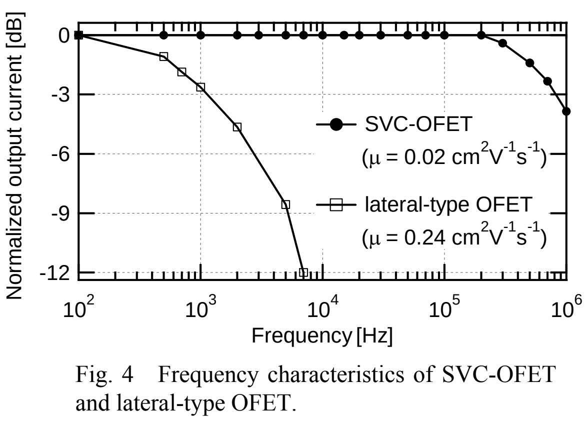

Fig. 4 Frequency characteristics of SVC-OFET and lateral-type OFET.

film and frequency characteristics. We applied self-assembled monolayer of 1,1,1,3,3,3-hexamethyldisilazan（HMDS）[8] between pentacene and SiO_2 layer. The HMDS surface modification improves f_c toward higher frequency around 900 kHz as shown in Fig. 4. The f_c obtained here is very high value comparing other type of OFETs.

4. Summary

New type OFETs with short channel length (SVC-OFETs) have been fabricated and investigated the basic characteristics. SVC-OFETs showed excellent device performances and high cut off frequency approximately 900 kHz was obtained. These results demonstrate that SVC-OFETs have a potential to produce an active-matrix display elements with a simple fabrication process.

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